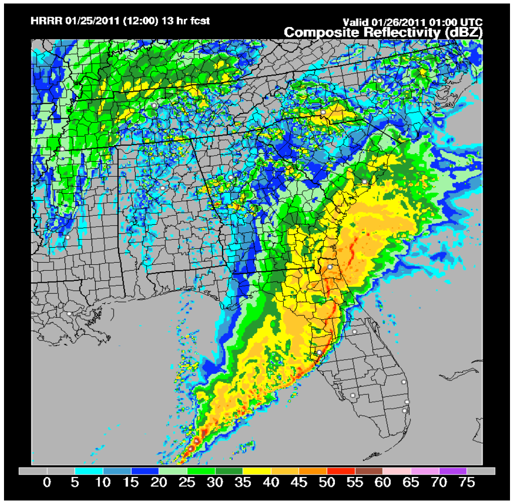
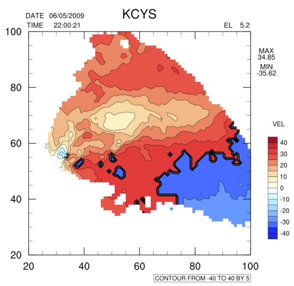
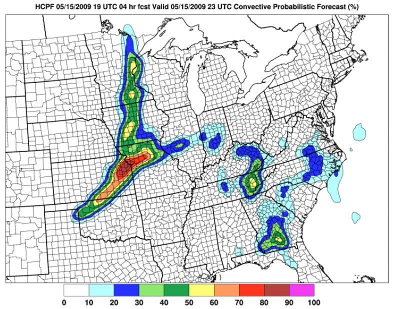
Warn-on-Forecast Accomplishments and Plans: NOAA ESRL Global Systems Division

GSD-AMB: David Dowell

GSD: Steve Koch
GSD-AMB: Stan Benjamin, Steve Weygandt, Ming Hu, Tanya Smirnova, Curtis Alexander, Joe Olson, John Brown, Kevin Brundage, Tracy Lorraine Smith, Georg Grell, Bill Moninger, Brian Jamison, Susan Sahm, Haidao Lin, Steven Peckham, Eric James, Patrick Hofmann
GSD-ISB: Patty Miller, Woody Roberts, Ron Lowther
NCAR: Glen Romine, Chris Snyder







Earth System Research Laboratory
SCIENCE, SERVICE & STEWARDSHIP

WoF Workshop, Norman, OK, 23 Feb 2011

Hourly Updated NOAA NWP Models

Rapid Refresh (RR) replaces RUC at NCEP in 2011: **WRF**, **GSI** + RUC-based enhancements, new 18h fcst every hour

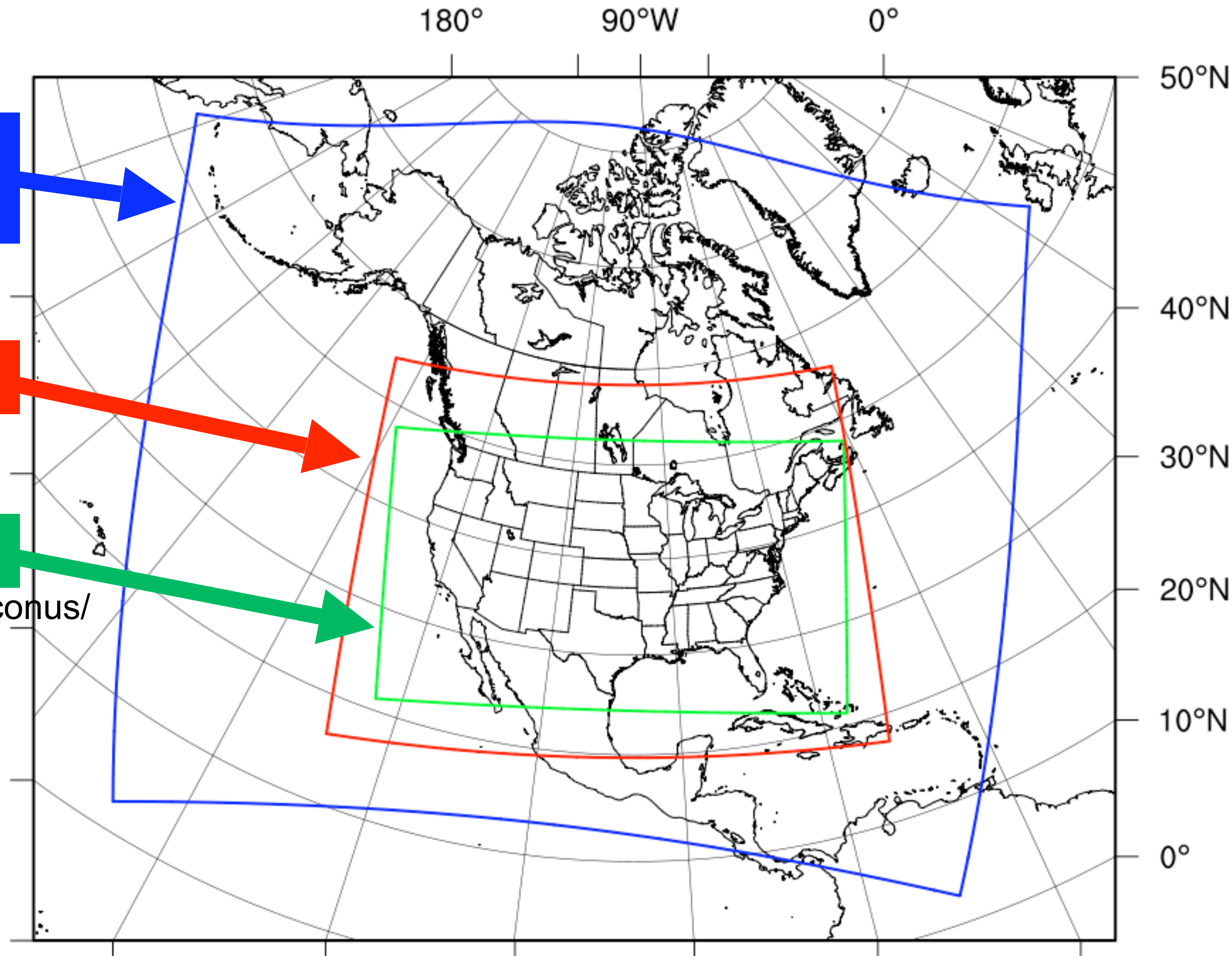
13km Rapid Refresh

rapidrefresh.noaa.gov/RR/

13km RUC

3km HRRR

rapidrefresh.noaa.gov/hrrrconus/

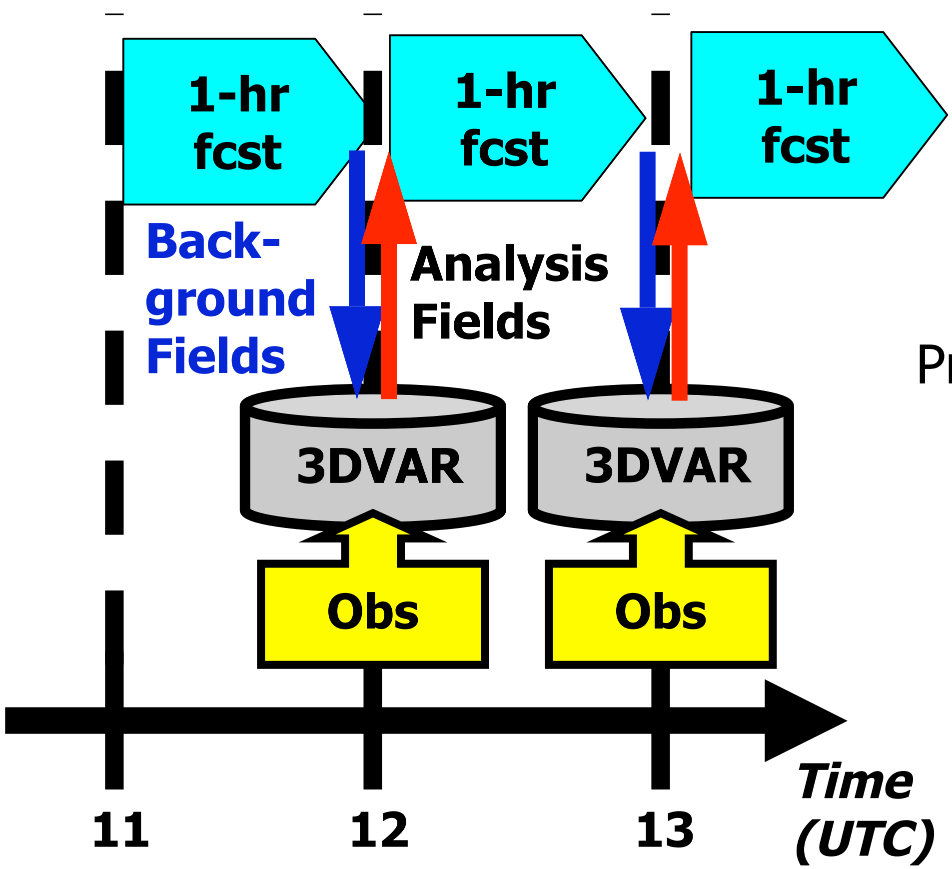


High-Resolution Rapid Refresh

Experimental 3km nest inside RUC or RR, new 15-h fcst every hour

Rapid Refresh: Hourly WRF-ARW 13-km Analyses and Forecasts

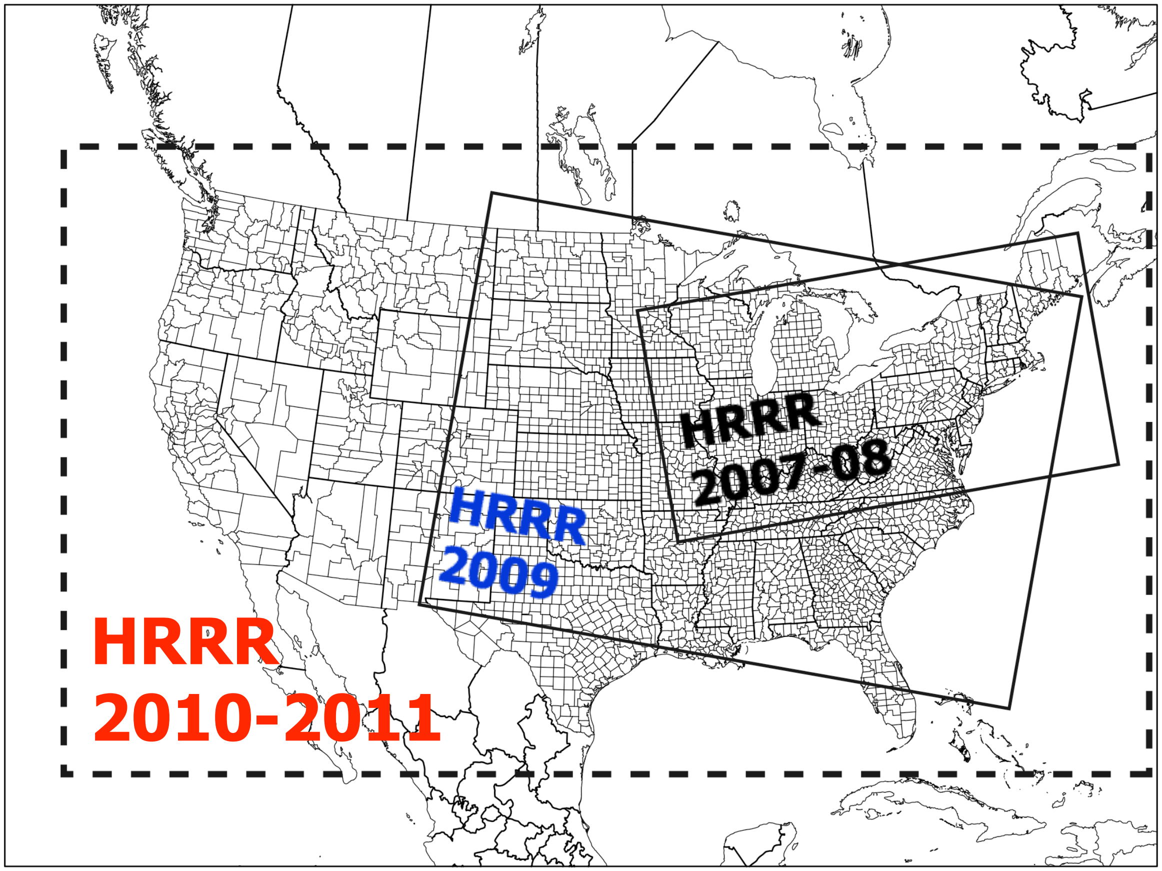
Hourly updating using all available observations



Data types used

Rawinsonde (balloons)
Wind Profilers (405 MHz, 915 MHz)
RASS virtual temperatures
VAD winds (WSR-88D radars)
Aircraft (ACARS, TAMDAR)
Surface (METAR, Buoy, Mesonet)
Precipitable water (GPS, GOES, SSM/I)
GOES cloud-drift winds
GOES cloud-top pressure/temp
Radar reflectivity, lightning
Ship reports/dropsondes
Satellite radiances

High Resolution Rapid Refresh (HRRR): Hourly 3-km (Analyses and) Forecasts



HRRR Milestones

2007: Inception northeastern US

Late 2009: Domain expanded to CONUS

2010: WRF-ARW v3.2

2010: Forecast period extended to 15 hrs

2010: ~95% reliability

Late 2010: Latency ~2 hrs

HRRR initialization:

- From RUC analysis currently; from RR analysis starting this spring
- No additional DA on 3-km grid currently; radar DA on 3-km grid soon

Year One* Activities and Deliverables

1. Develop code necessary to provide output from the High-Resolution Rapid Refresh (HRRR) model every 15 min during the 0-3 forecast.

- Transition to GRIB2 for all output
  much smaller file sizes than for GRIB1

- GRIB2 sub-hourly output generated for a test case
  success with Unipost for 15-min output
  GRIB issues with time conventions for sub-hourly output

- Approximately 20 fields in 2D output
  requests for additional fields welcomed from W-o-F partners
  data to be made available by ftp

- 3D output available upon request for specific cases
  files too large to be made available regularly on ftp server

*** March 2010 - February 2011**

Year One Activities and Deliverables

2. Test direct application of the digital filter initialization (DFI) radar DA at the 3-km HRRR resolution.

- Temperature tendency based on observed reflectivity, applied during forward model integration
- Digital filter applied after model integration, to reduce noise

- Technique used to initialize 13-km models (RUC, RR)
- Method now being tested for HRRR (3-km) initialization

- Inexpensive method for initializing small scales

Note: Doppler velocity data assimilation, which is needed for W-o-F and desired for the HRRR, will also be tested in the near future.

Diabatic Digital Filter Initialization (DDFI)

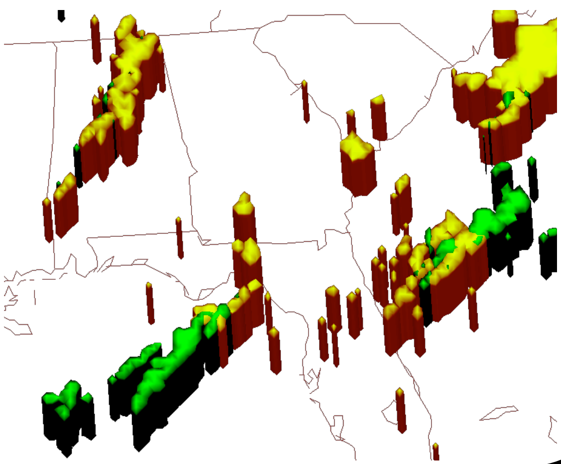
Technique for assimilating reflectivity data into the HRRR will be somewhat like that currently used to assimilate reflectivity data into the 13-km models (RR and RUC)

-2Δ min **-Δ min** **Init** **+Δ min**

Δ ~ 10 min

Backward integration, no physics

Forward integration, full physics



Apply latent heating from radar reflectivity, lightning data

Obtain initial fields with improved balance, vertical circulations associated with ongoing convection

RUC/RR/HRRR model forecast

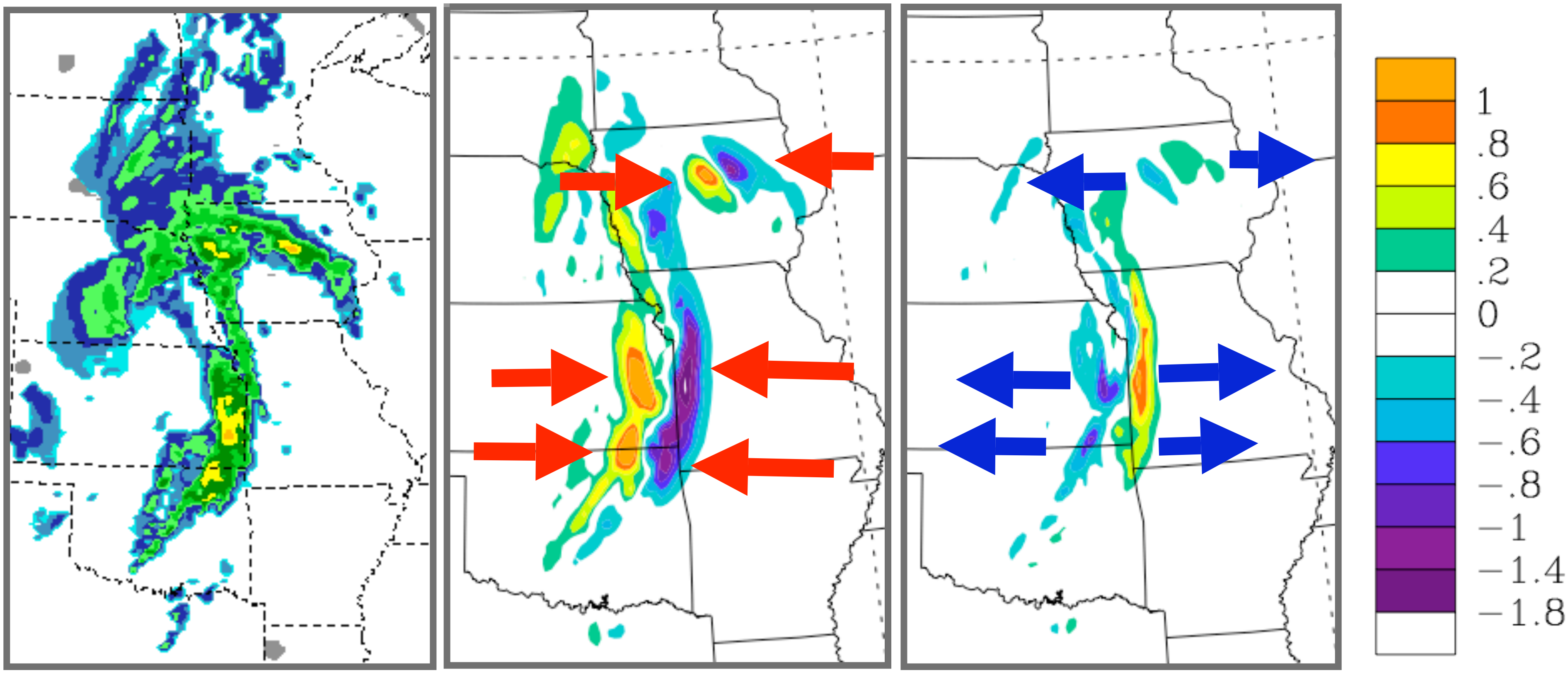
Radar reflectivity assimilation in RUC, RR, and now HRRR

Rapid Refresh reflectivity assim. (DDFI) example

NSSL radar reflectivity (dBZ)

Low-level Convergence
(induced by temperature forcing)

Upper-level Divergence
(induced by temperature forcing)

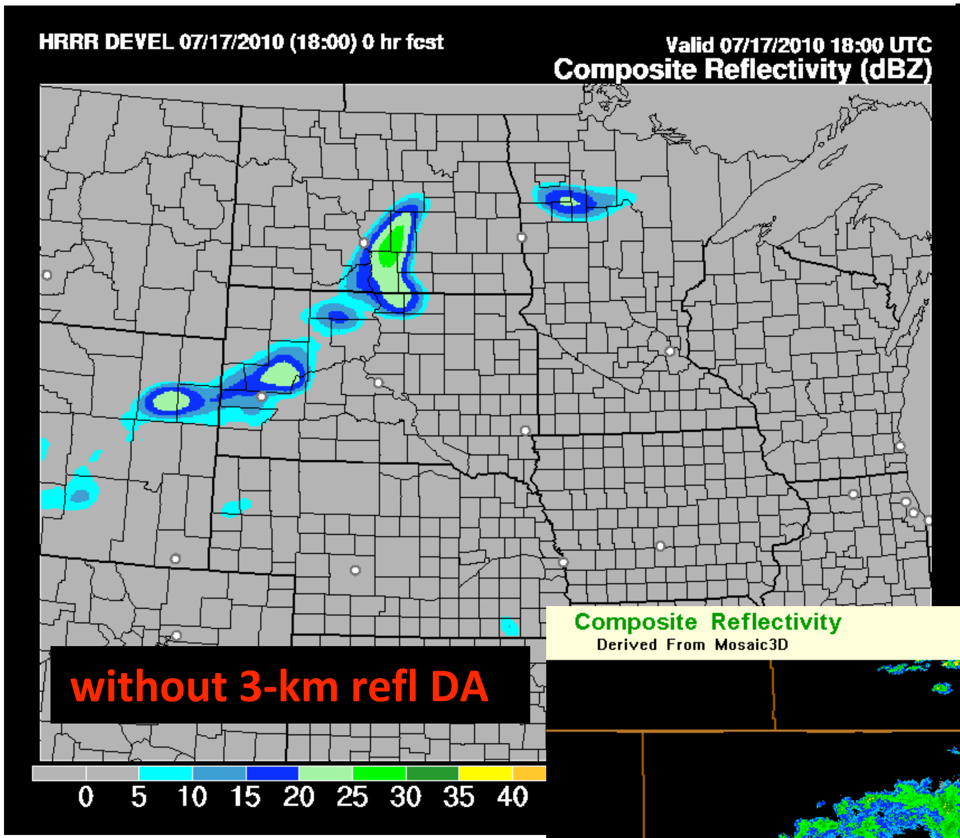


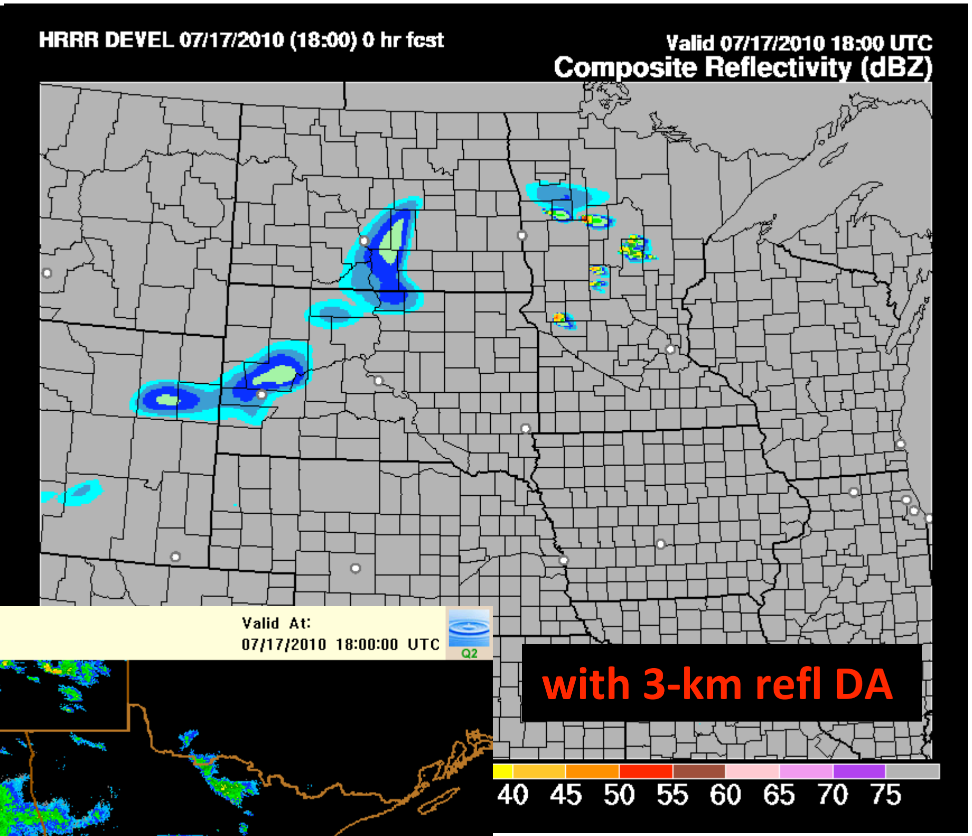
14z 22 Oct 2008
Z = 3 km

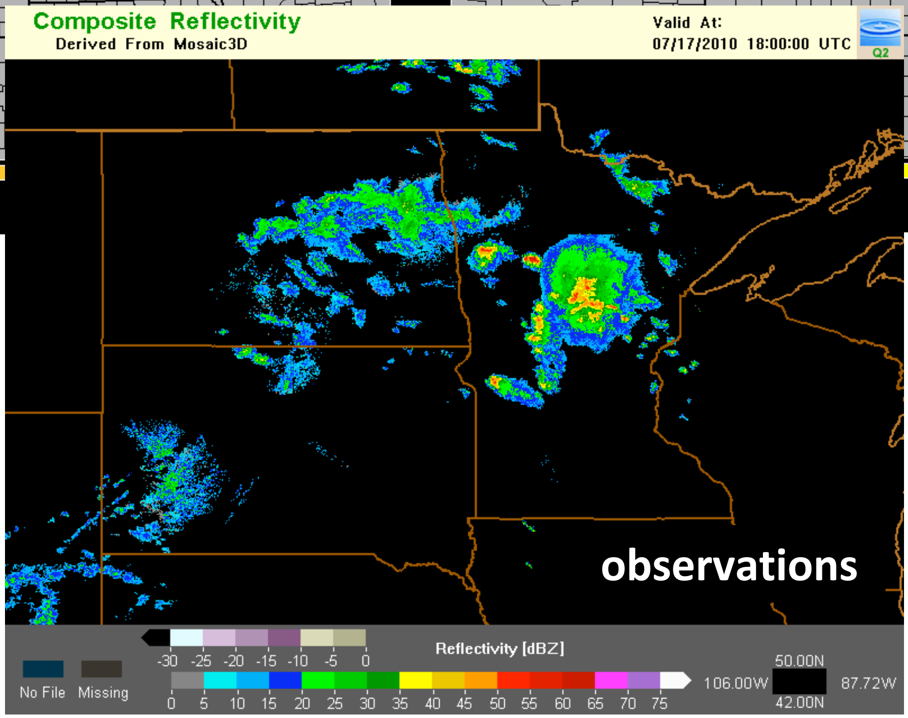
K=4 U-comp. diff
(radar - norad)

K=17 U-comp. diff
(radar - norad)

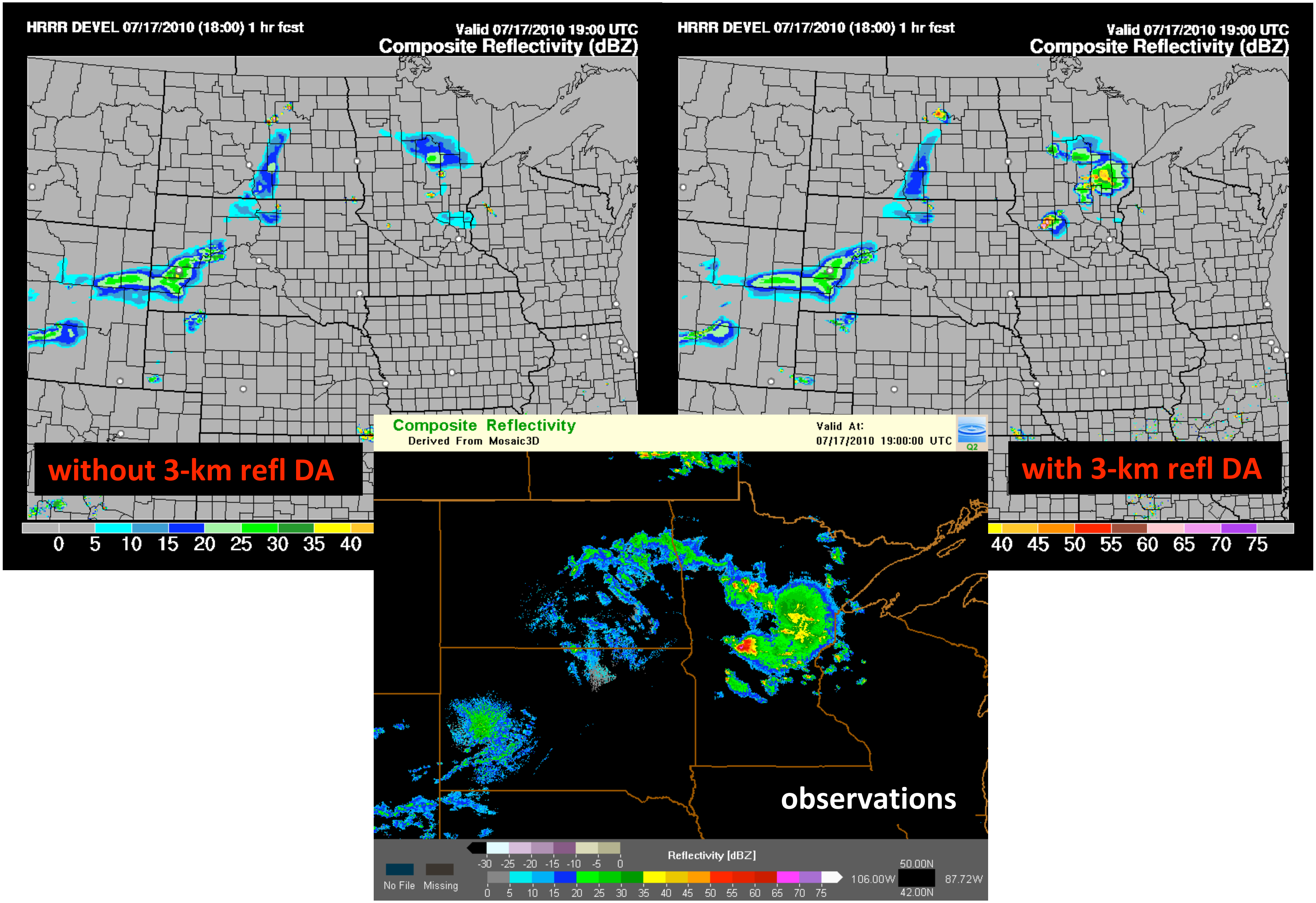
3-km Reflectivity DA (DDFI) Experiment: Initialization Time



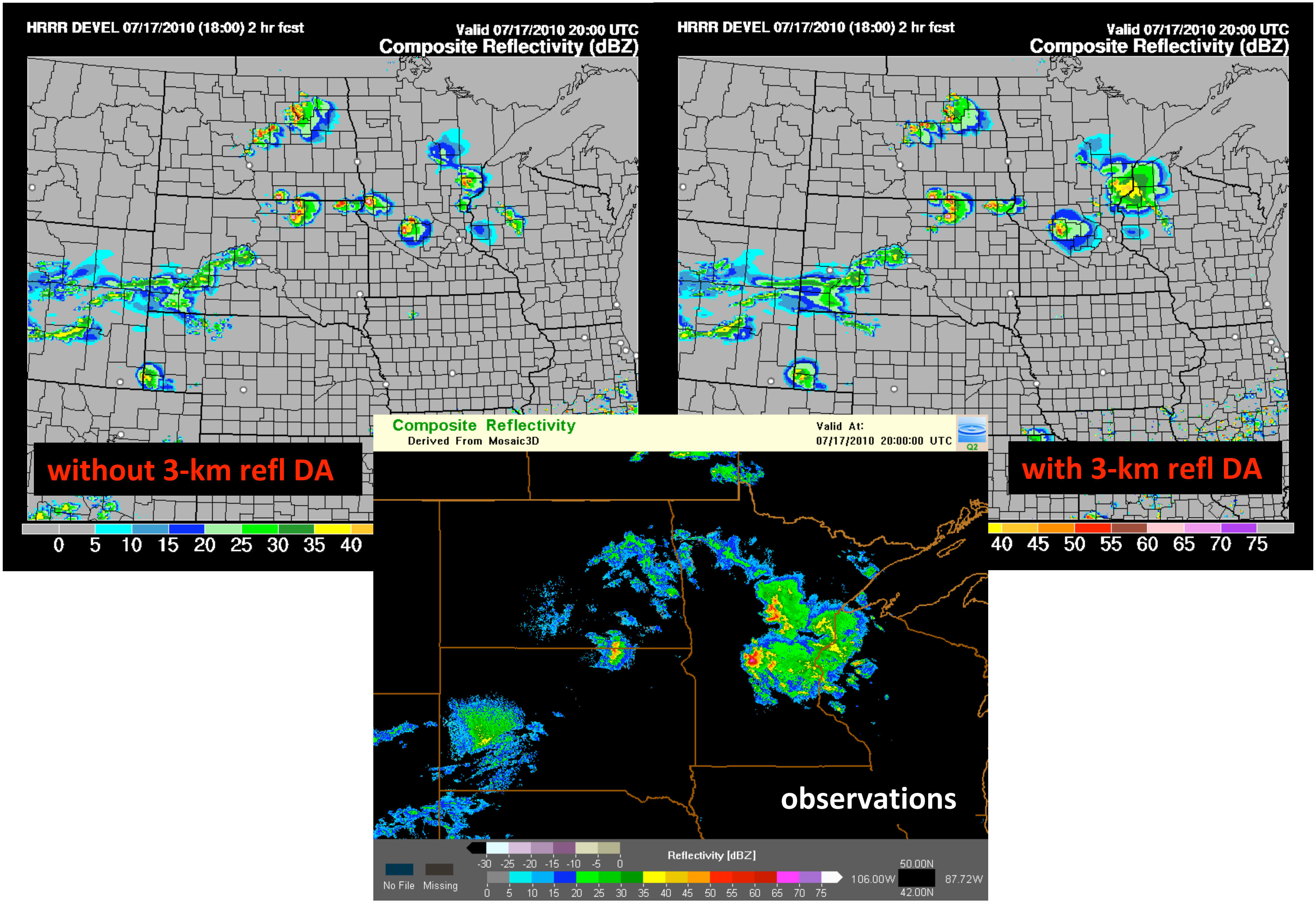




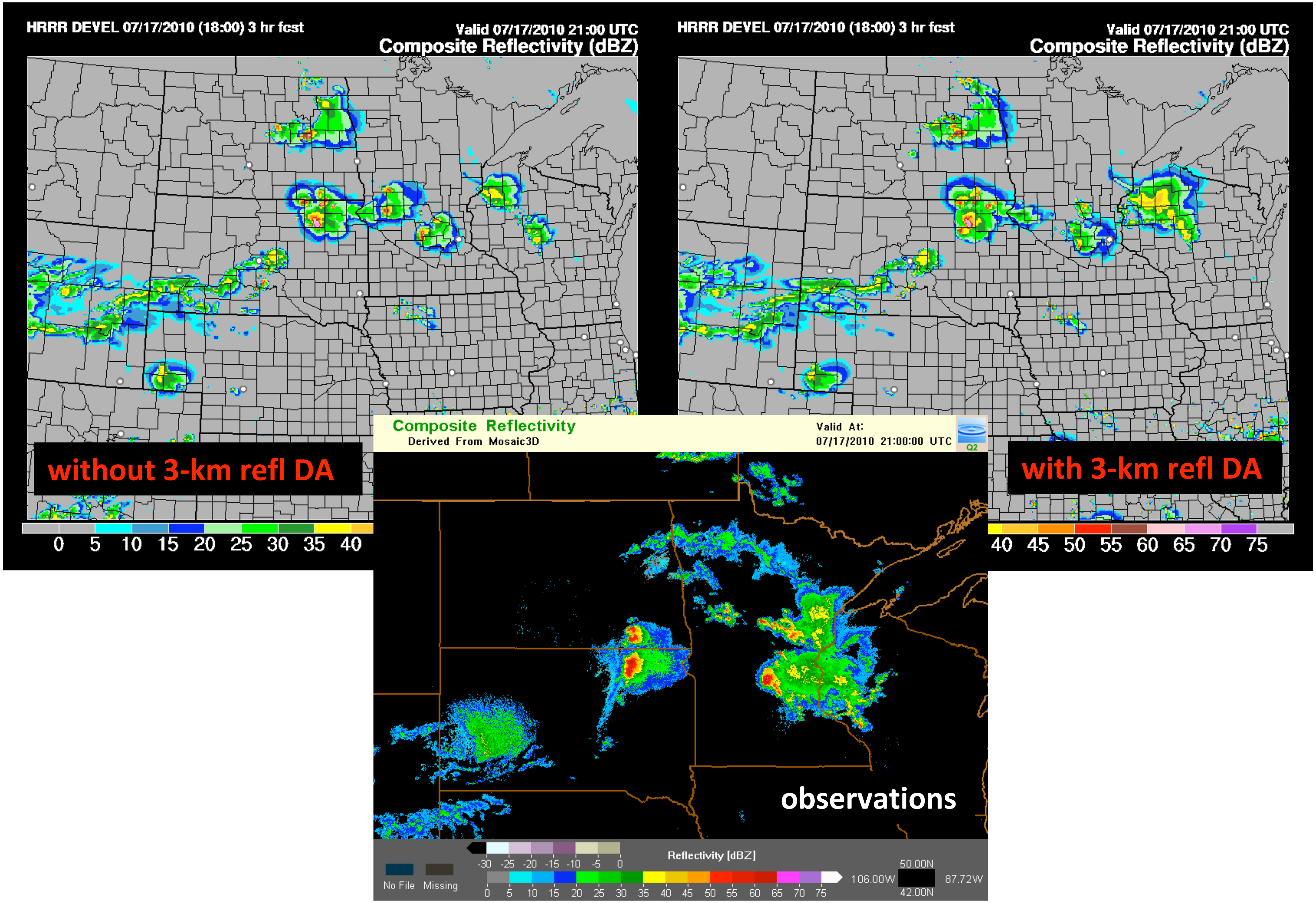
3-km Reflectivity DA (DDFI) Experiment: 1-hr Forecast



3-km Reflectivity DA (DDFI) Experiment: 2-hr Forecast



3-km Reflectivity DA (DDFI) Experiment: 3-hr Forecast



Year One Activities and Deliverables

3. Hire a federal scientist with expertise in data assimilation for convective scales to help lead the warn-on-forecast efforts.

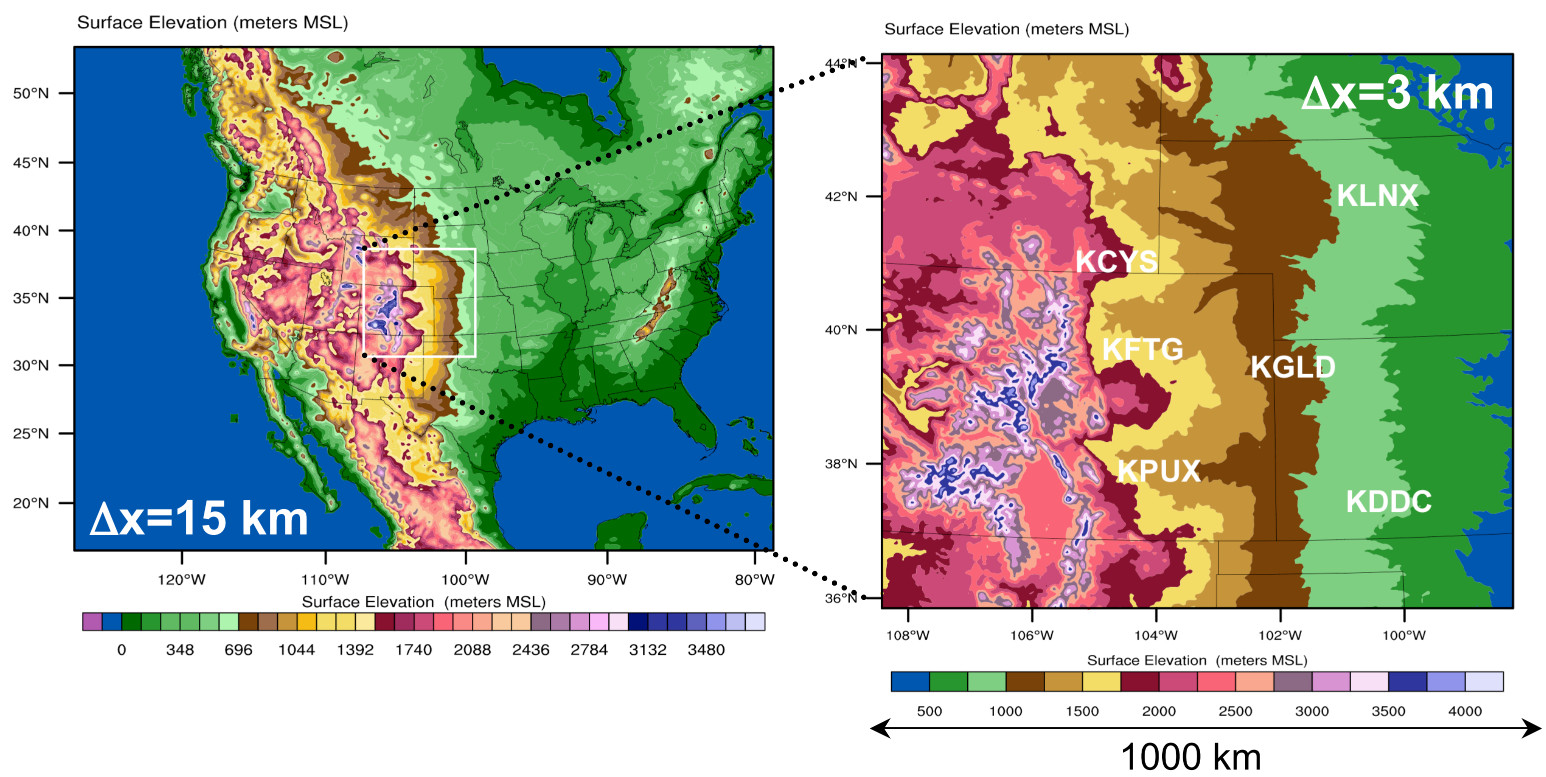
D. Dowell joined the project in late October after recovering from VORTEX2.

Year One Activities and Deliverables

4. Collaborate with other project partners in exploring complex issues related to the frequent updating of convective-scale models, both deterministic and ensemble systems.

June 2009 retrospective study (Glen Romine, David Dowell, Chris Snyder)

- Demonstration of current EnKF (WRF-DART) capabilities
- Mesoscale (Δx=15 km) CONUS domain: successful cycling for 18 days (radisonde, surface, aircraft, and satellite wind obs every 3 h)

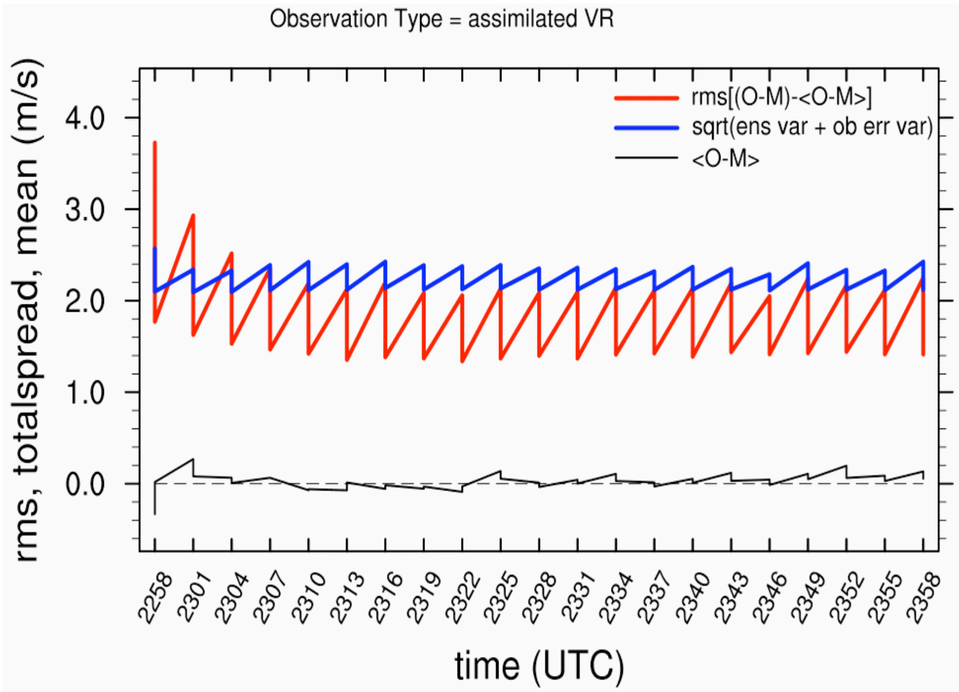


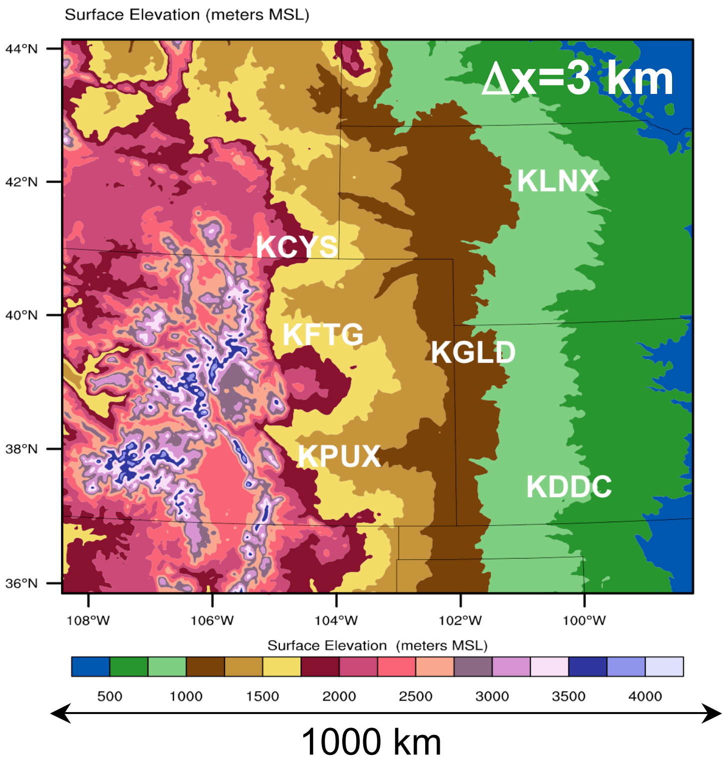
Year One Activities and Deliverables

4. Collaborate with other project partners in exploring complex issues related to the frequent updating of convective-scale models, both deterministic and ensemble systems.

June 2009 retrospective study (Glen Romine, David Dowell, Chris Snyder)

- Storm-scale (Δx=3 km) high plains domain: assimilation of WSR-88D Doppler velocity and reflectivity obs every 3 min for 1 hour, followed by 6-hour, 50-member ensemble forecast





Year One Activities and Deliverables

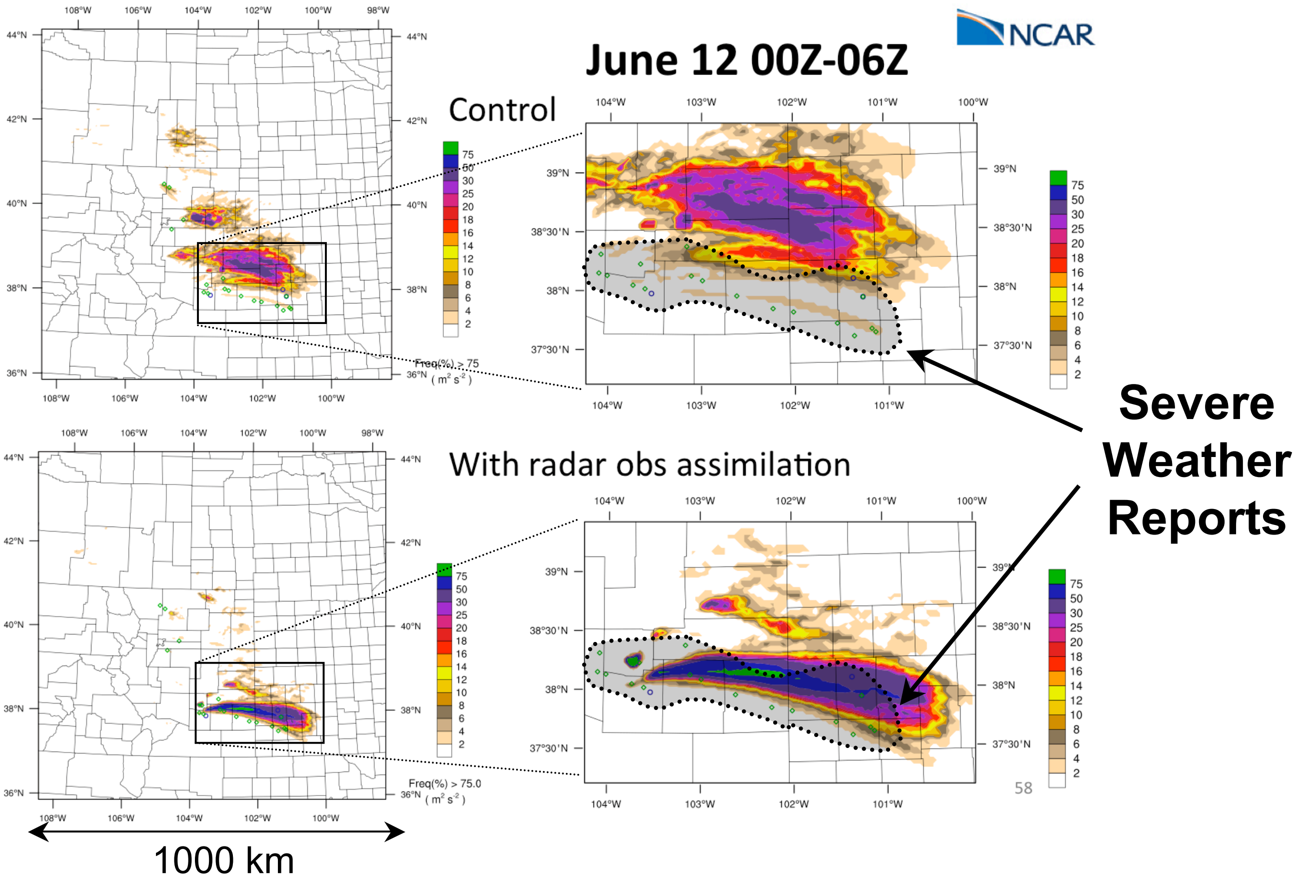
4. Collaborate with other project partners in exploring complex issues related to the frequent updating of convective-scale models, both deterministic and ensemble systems.

June 2009 retrospective study (Glen Romine, David Dowell, Chris Snyder)

Probability of Rotating Updrafts, 6-Hour Ensemble Forecast

Control (no radar DA)

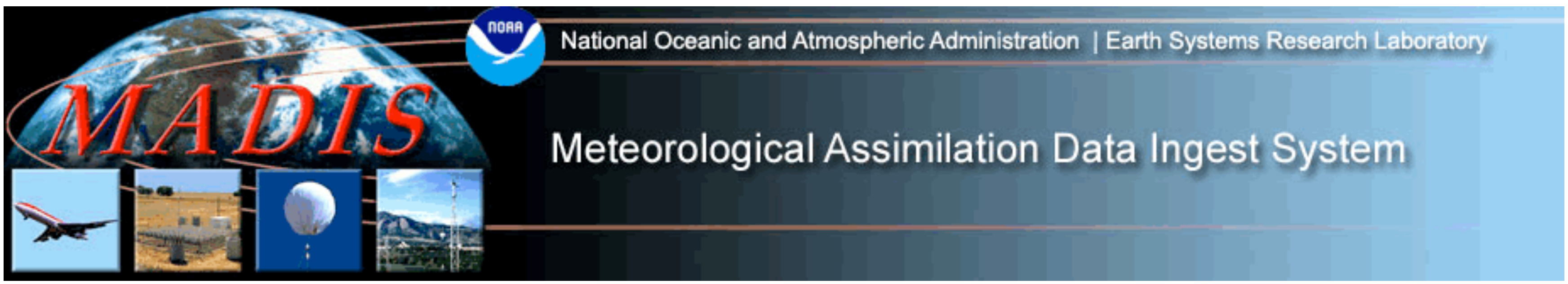
With radar DA



Year One Activities and Deliverables

5. Compute model-to-observation statistics for the Rapid Refresh / HRRR models using observations provided by the Meteorological Assimilation Data Information System (MADIS) and incorporate the statistics into the National Mesonet database along with the station and instrumentation information.

http://madis.noaa.gov/

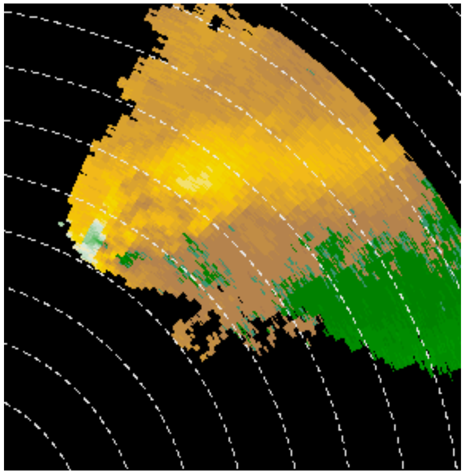


- "National Mesonet" data are now being ingested into the MADIS.
- New observations and metadata from other stationary and mobile observing platforms will also be ingested.
- A "use list", which includes the Alaska mesonet, is being developed for the Rapid Refresh (RR) model.

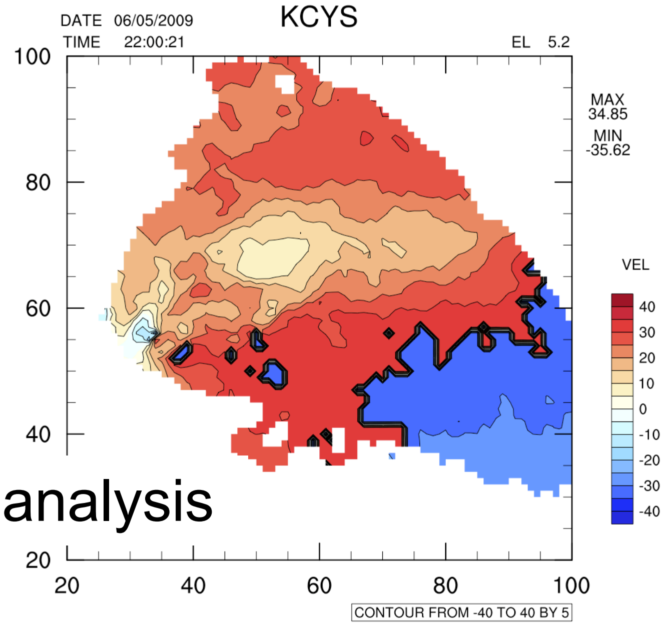
Year One Activities

Observation Processing and Wind Synthesis (OPAWS) software http://code.google.com/p/opaws/

- Tools for radar-data quality control, objective analysis, preparation for data assimilation
- Recent code upgrade (multiple radar-data formats, Fortran namelist input, modular design) by D. Dowell and L. Wicker
- Code now available online



raw velocity data



objective analysis

Year One Activities

HRRR Convective Probability Forecast (HCPF)

http://ruc.noaa.gov/hcpf/hcpf.cgi

- Probability provided by HRRR "ensemble of opportunity": *forecasts initialized at different times but valid at the same time*
  - 15-h forecasts produced every 1 h
- Not a Warn-on-Forecast activity, but relevant to our project
  - ensemble post-processing, display concepts, etc.

Identification of moist convection from model forecast fields:

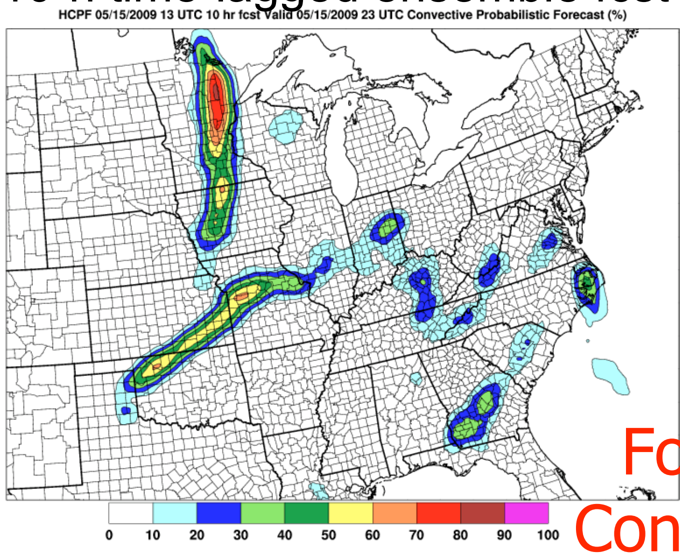
- **Stability – Surface lifted index < +2°C (neutral to unstable)**
- **Intensity – Max vertical velocity in model column > ~1 m s^{-1}**
- **Time – 2 hr search window centered on valid times**
- **Location – Stability and intensity criteria searched within 30 points (radius of ~90 km) of each point for each member**

$$\text{HCPF} = \frac{\text{\# grid points matching criteria over all members}}{\text{total \# grid points searched over all members}}$$

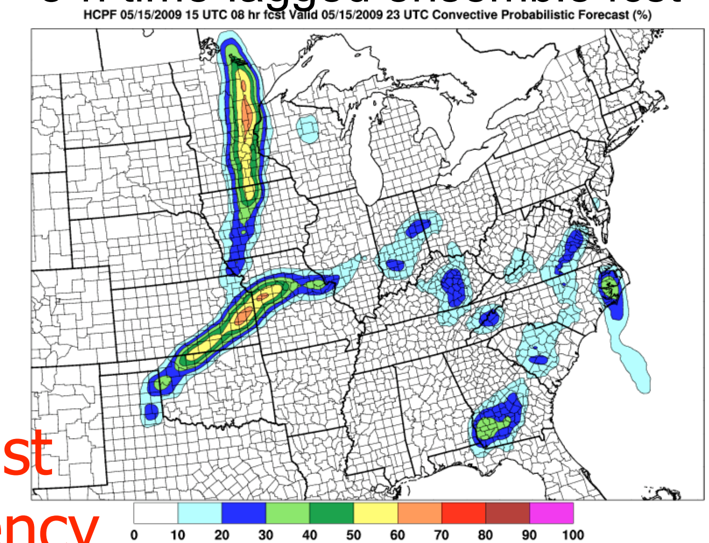
Year One Activities

HCPF example: 2300 UTC 15 May 2009

10-h time-lagged ensemble fcst

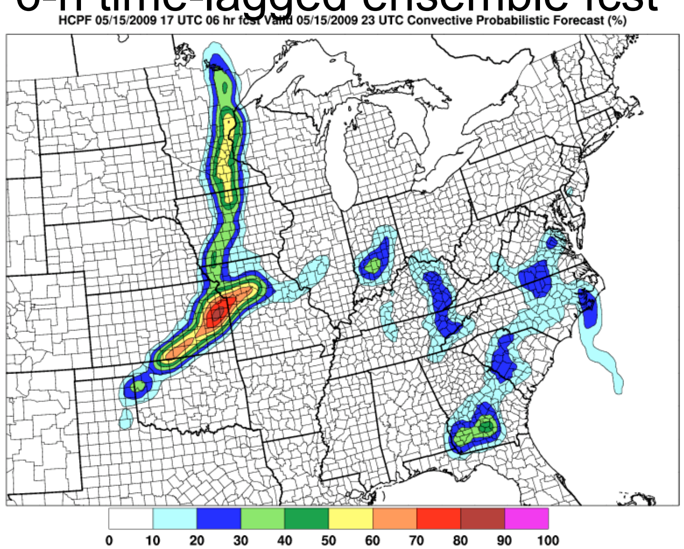


8-h time-lagged ensemble fcst

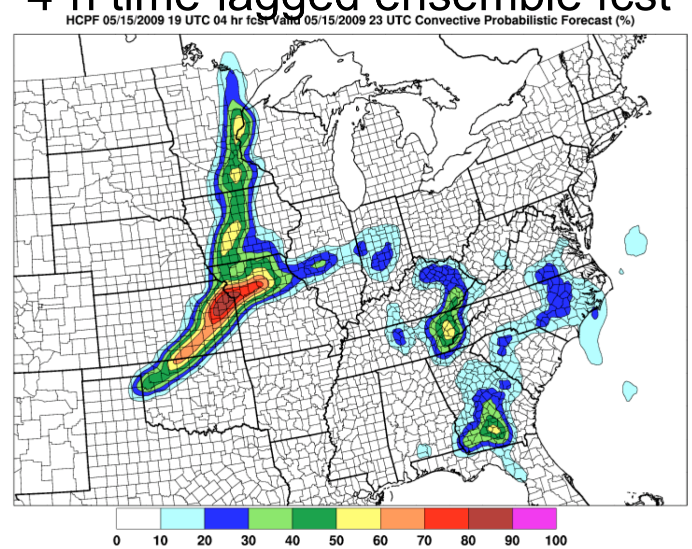


Forecast Consistency

6-h time-lagged ensemble fcst



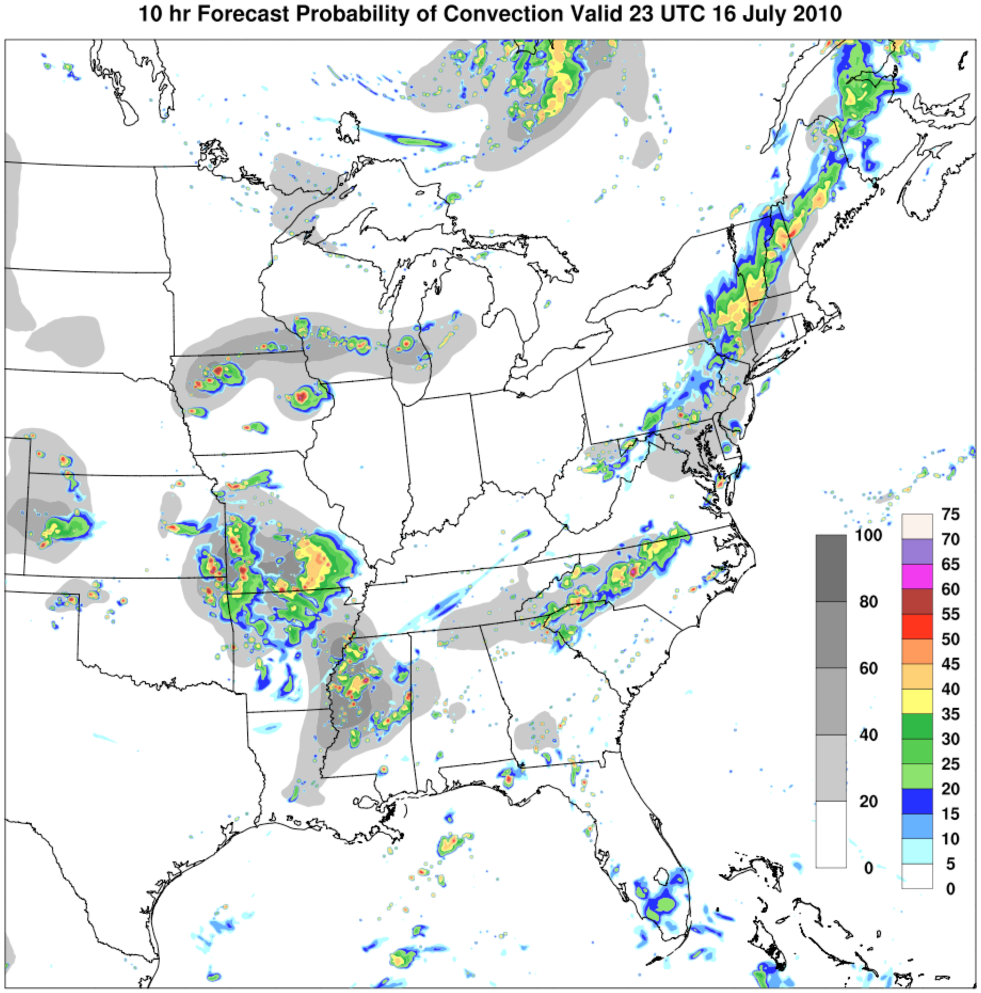
4-h time-lagged ensemble fcst



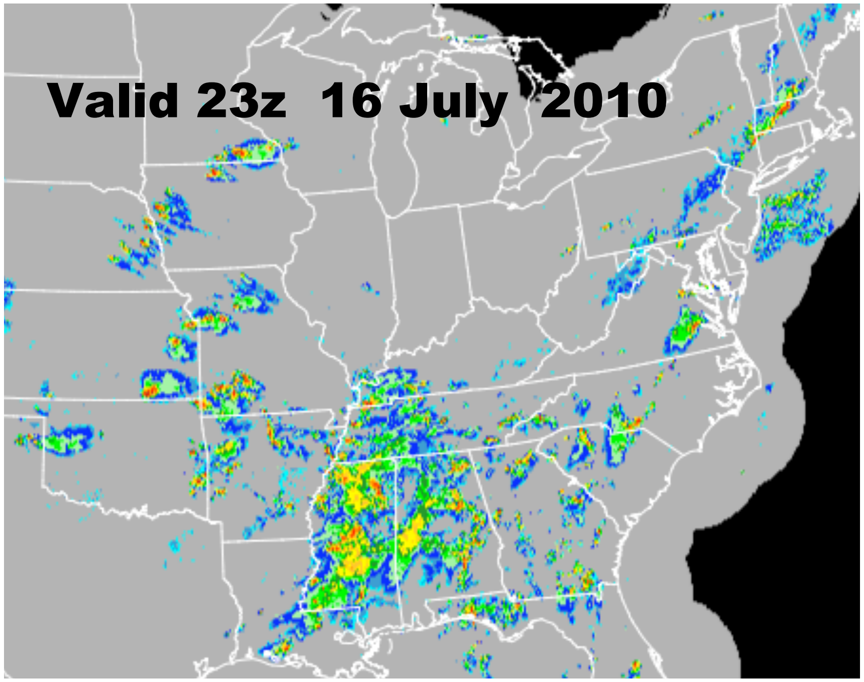
Year One Activities

HRRR Convective Probability Forecast: display concepts

10-h fcst. prob. of convection, composite reflectivity from a deterministic forecast



observed composite reflectivity

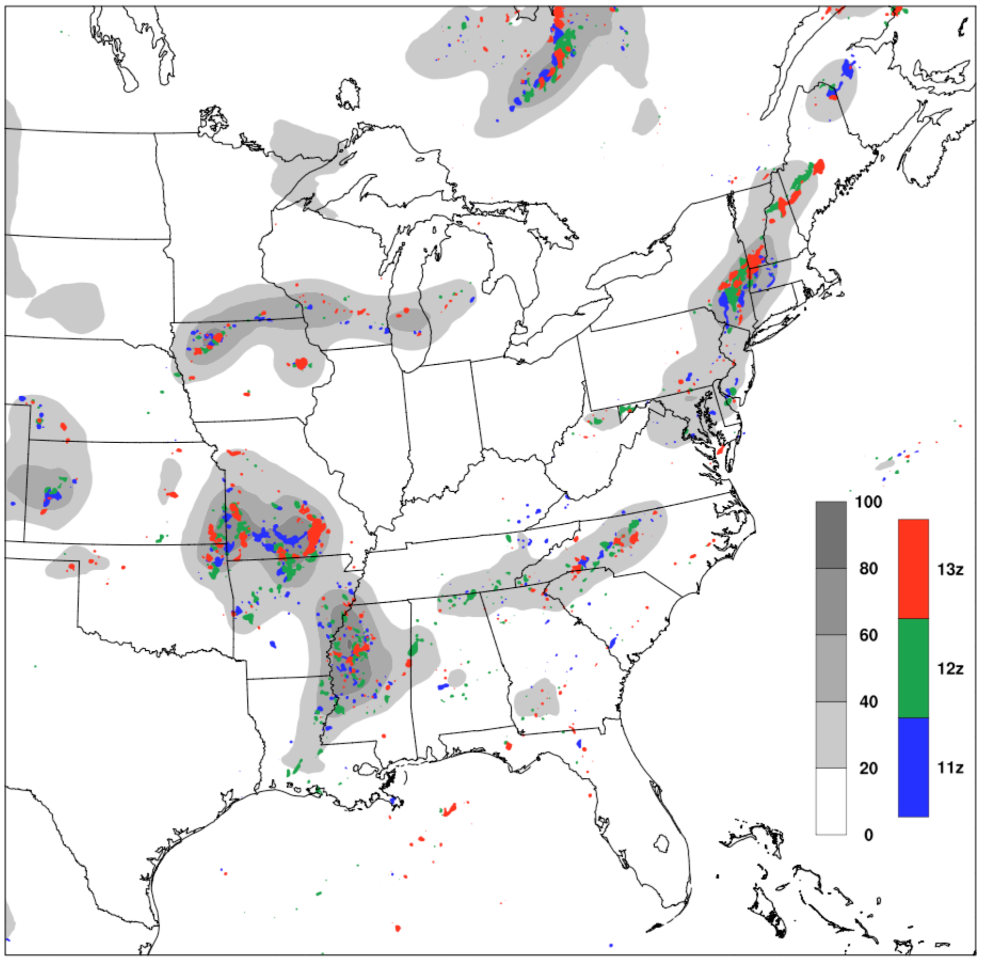


Year One Activities

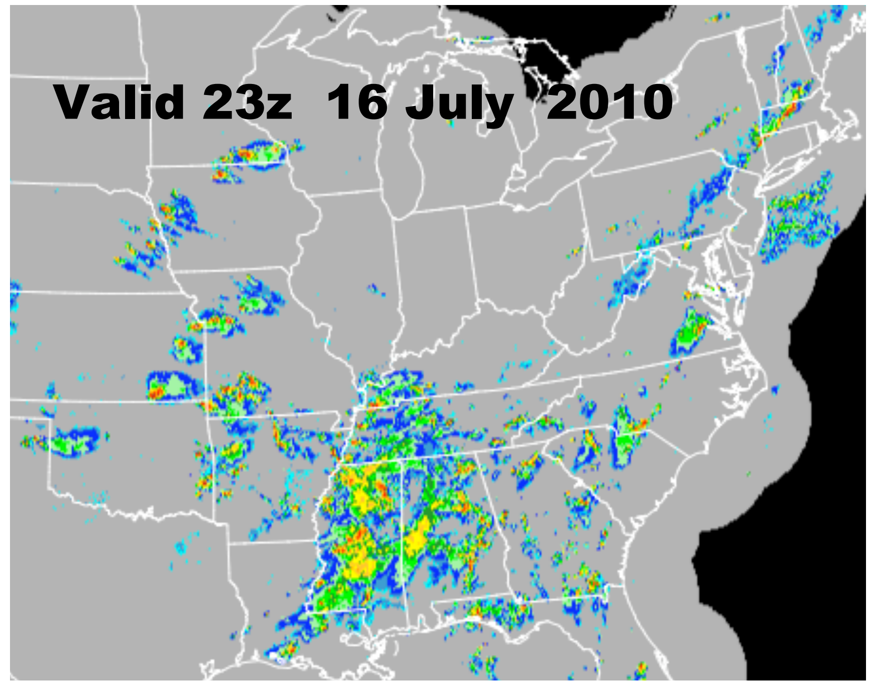
HRRR Convective Probability Forecast: display concepts

10-h fcst. prob. of convection, storm (high refl.) locations in 3 deterministic forecasts

10 hr Forecast Probability of Convection Valid 23 UTC 16 July 2010



observed composite reflectivity



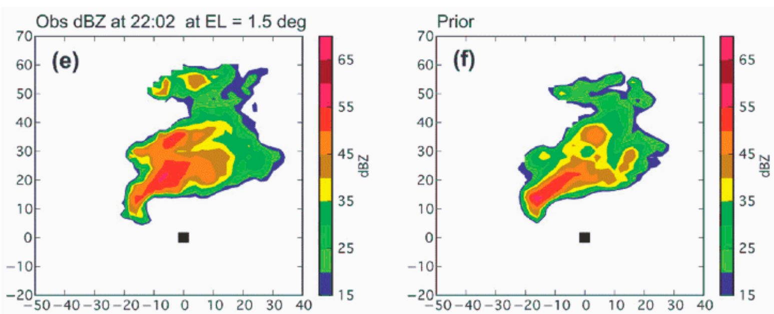
Year One Activities

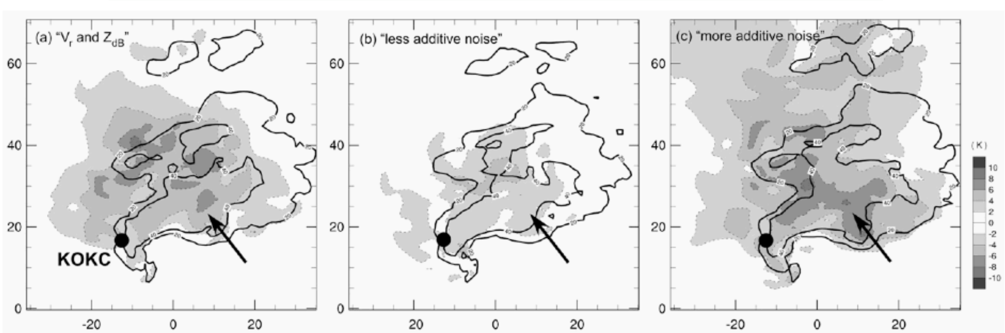
Storm-scale reflectivity data-assimilation study

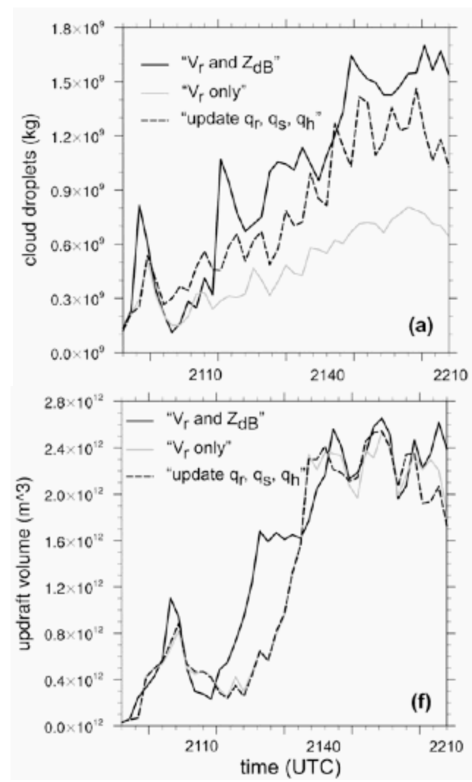
Dowell, D. C., L. J. Wicker, and C. Snyder, 2011: Ensemble Kalman filter assimilation of radar observations of the 8 May 2003 Oklahoma City supercell: Influences of reflectivity observations on storm-scale analyses. *Mon Wea Rev.*, 272-294.

Pros and cons of reflectivity DA:

- more rapid storm development in model (cloud water, vertical velocity) than when only Doppler velocity data are assimilated
- bias errors (model microphysics, observations, observation operators) projected onto all state variables
- cold-pool sensitivity to details of DA, ensemble design







Proposed Year Two* Activities

RR and HRRR model enhancement

These models are a proposed "backbone" (providing initial and/or boundary conditions) for nested Warn-on-Forecast systems.

- Transition from Rapid Update Cycle (RUC) to Rapid Refresh (RR) as parent model for HRRR (spring 2011)
- Real-time implementation of 3-km reflectivity DA (spring 2011)

- "Development HRRR"
  - Runs every 3 h, opportunity to test new ideas for DA and model config.
  - Assimilation of SatCast and Doppler velocity data
  - Model and DA changes targeting known HRRR issues (low bias Southeast US ordinary storms, difficulty maintaining MCSs, lag in CI in early runs, false alarms)

* March 2011 - February 2012

Future plans for advanced hourly NWP/DA

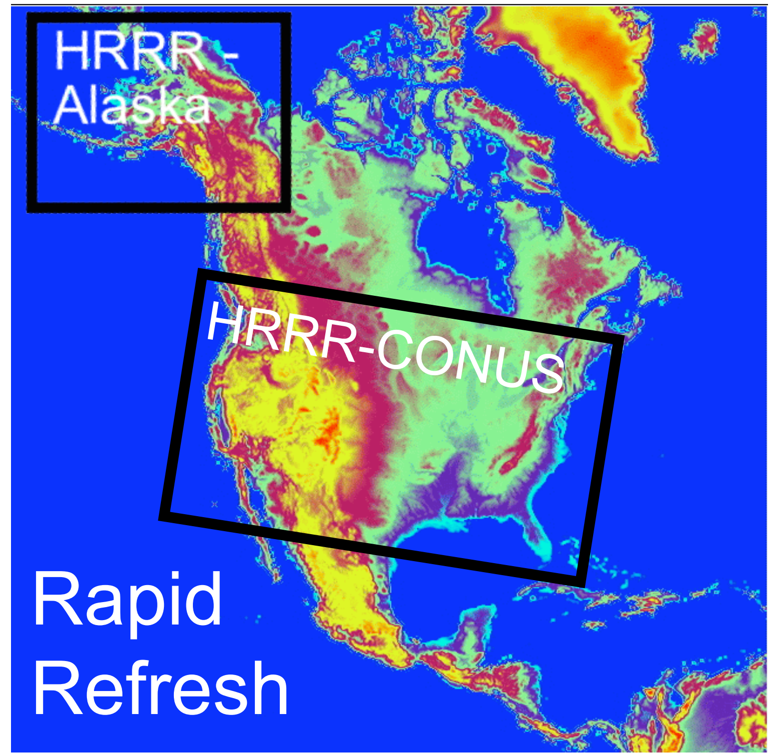
2011 – Rapid Refresh operational at NCEP

2011-14 – HRRR demo @ESRL improves

2014 – Ensemble Rapid Refresh – NARRE

2014 – High-Resolution Rapid Refresh
operational at NCEP for CONUS

2016 – CONUS Ensemble HRRR - HRRRE



North American Rapid Refresh Ensemble

- NEMS-based NMM, ARW cores
- Hourly updating with GSI (hybrid-EnKF-GSI?)
- Initially 6 members, 3 each core
- Forecasts to 24-h
- NMM to 84-h 4x per day

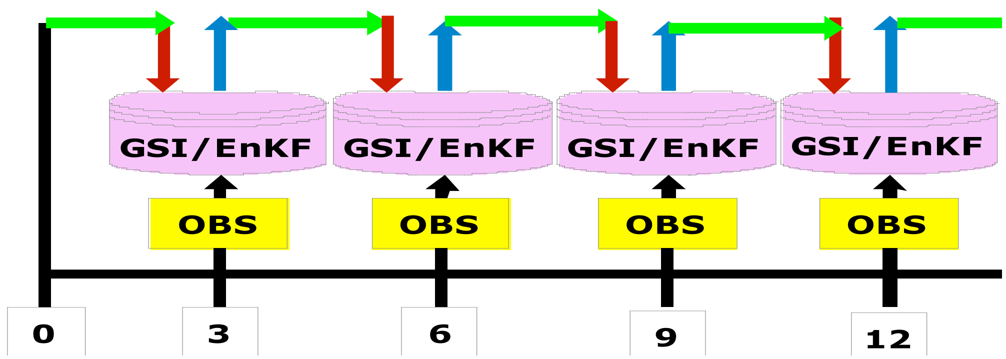
Other improvements

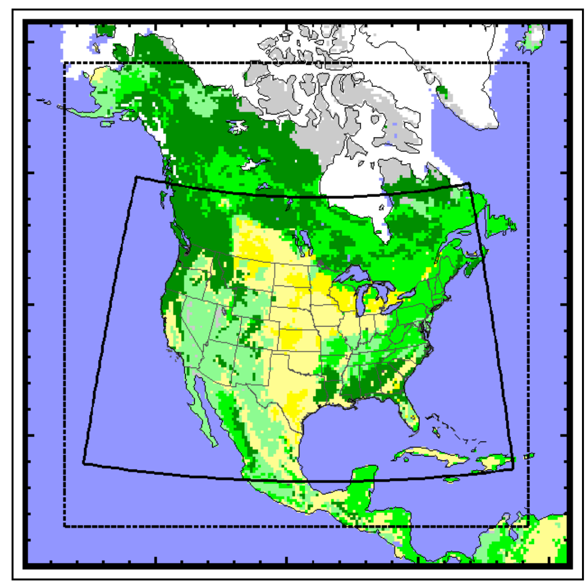
- Add inline chem, chem DA
- Storm-scale radar assimilation
- Sub-hourly DA

Proposed Year Two Activities

Continued collaboration with OU-CAPS on CONUS mesoscale (40-km) EnKF / hybrid system

- Kefeng Zhu, Xuguang Wang, Ming Xue, Jeff Whitaker
- Development and testing for May 2010 retrospective period
  - EnKF and GSI (3DVar) cycling
  - Innovation calculation with GSI
  - Tuning: inflation, localization





- Real-time implementation?
- Boundary conditions for a storm-scale system?

Proposed Year Two Activities

Feasibility study: 2012 storm-scale EnKF demo?
(postponed from year 1 to year 2)

- Advantages and disadvantages of an advanced method for storm-scale radar data assimilation
  - Small domain covered by one or a few radars
  - Side-by-side comparison of analyses and 0-2 h forecasts produced with EnKF and a simpler method (e.g., DDFI and/or 3DVar)
- Good opportunity for multi-institution collaboration (ESRL, NSSL, OU, NCAR)
  - Shared ideas for improving efficiency
  - RR, HRRR, mesoscale EnKF (NCAR, NSSL), and/or CAPS ensembles for initial conditions, boundary conditions, and ensemble perturbations?
  - Computing resources?
- Reducing the computational requirements of an EnKF system
  - Speculation: <10% of the computation does >90% of the “work”
  - Ideas from recent literature

Proposed Year Two Activities

(also postponed from year 1 to year 2)

Prototype a framework sufficient to perform an initial displaced real-time evaluation of warn-on-forecast techniques and capabilities.

deliverable: prototype system that can be used to assess techniques and capabilities

Document the operational procedures and uses of current AWIPS and N-AWIPS capabilities and functionality that support operational severe weather watch and warning programs.

deliverable: report documenting current WFO and SPC practices for determining and generating severe weather watches and warnings

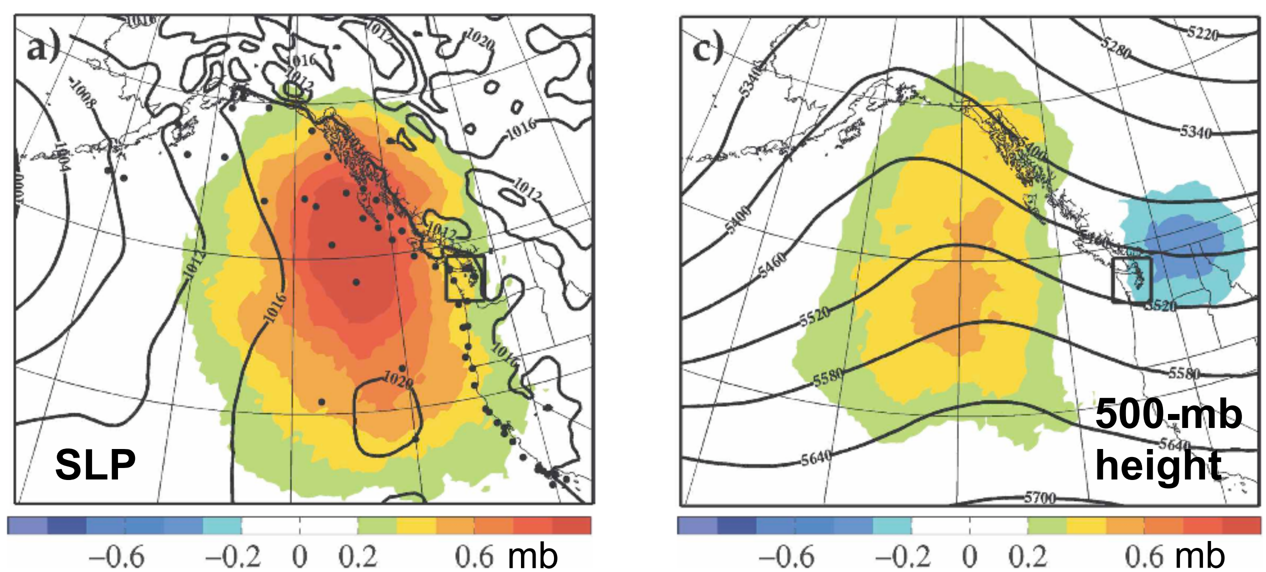
deliverable: collection of warning and verification information from selected WFOs

Proposed Year Two Activities

Storm-scale ensemble sensitivity analysis (ESA)

- Correlations between initial conditions (or model parameters) and forecast metrics
  - New method (Hakim and Torn 2008, Torn and Hakim 2008), applied so far only to larger scales
- What really affects 0-2 hour forecasts of convective storm strength / location / existence?
- To improve forecasts, where and what should we observe?

composite sensitivity for analysis field and 24-hr forecast SLP in western WA (Torn and Hakim 2008)

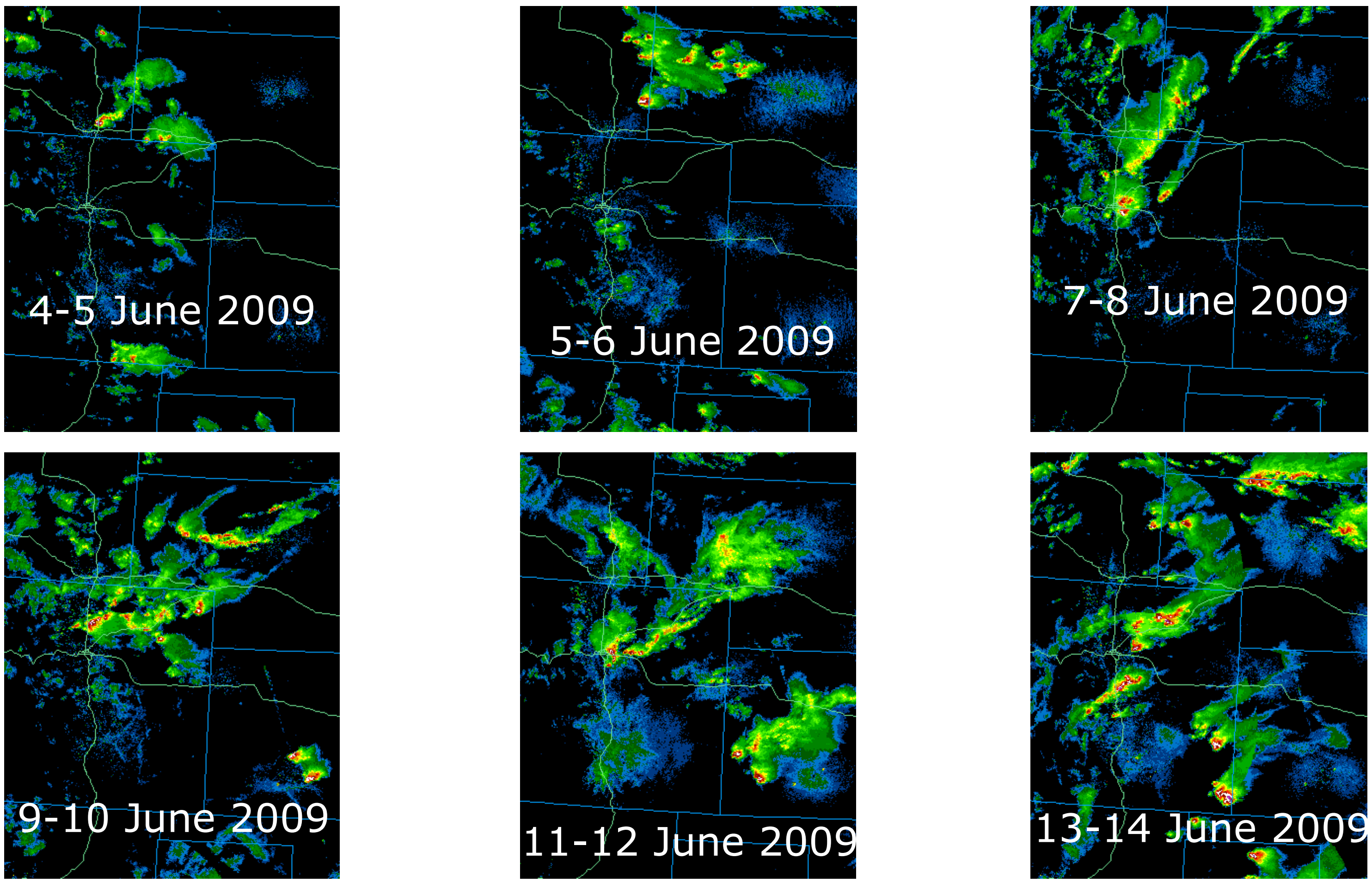


Proposed Year Two Activities

Collaboration with partners on VORTEX2 (2009-2010)

retrospective modeling and NWP

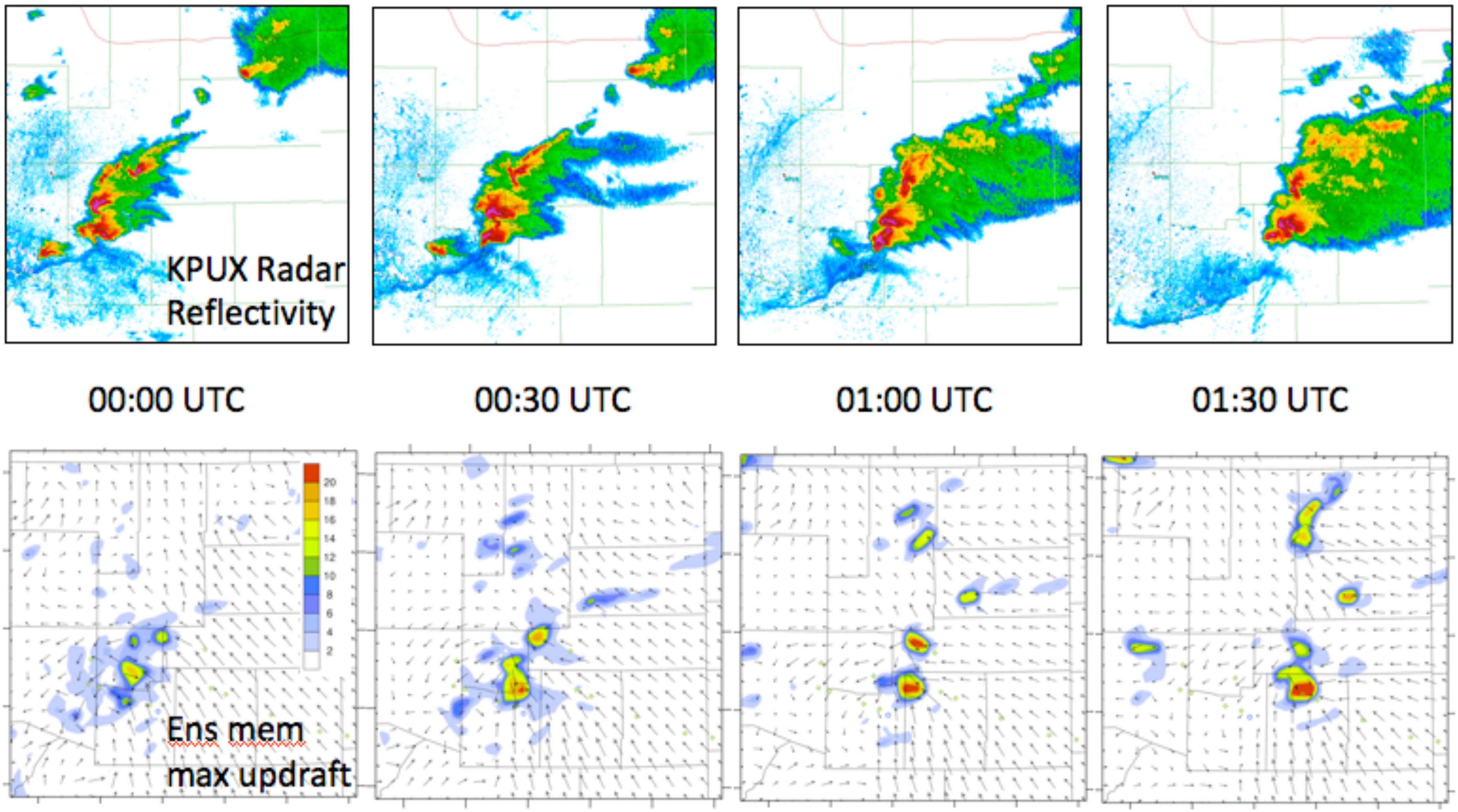
- Continued collaboration with Glen Romine and Chris Snyder at NCAR on June 2009 multi-case EnKF retrospective study (more cases; journal paper)
- More discussion of VORTEX2 this afternoon



Warn-on-Forecast Accomplishments and Plans: NOAA ESRL Global Systems Division

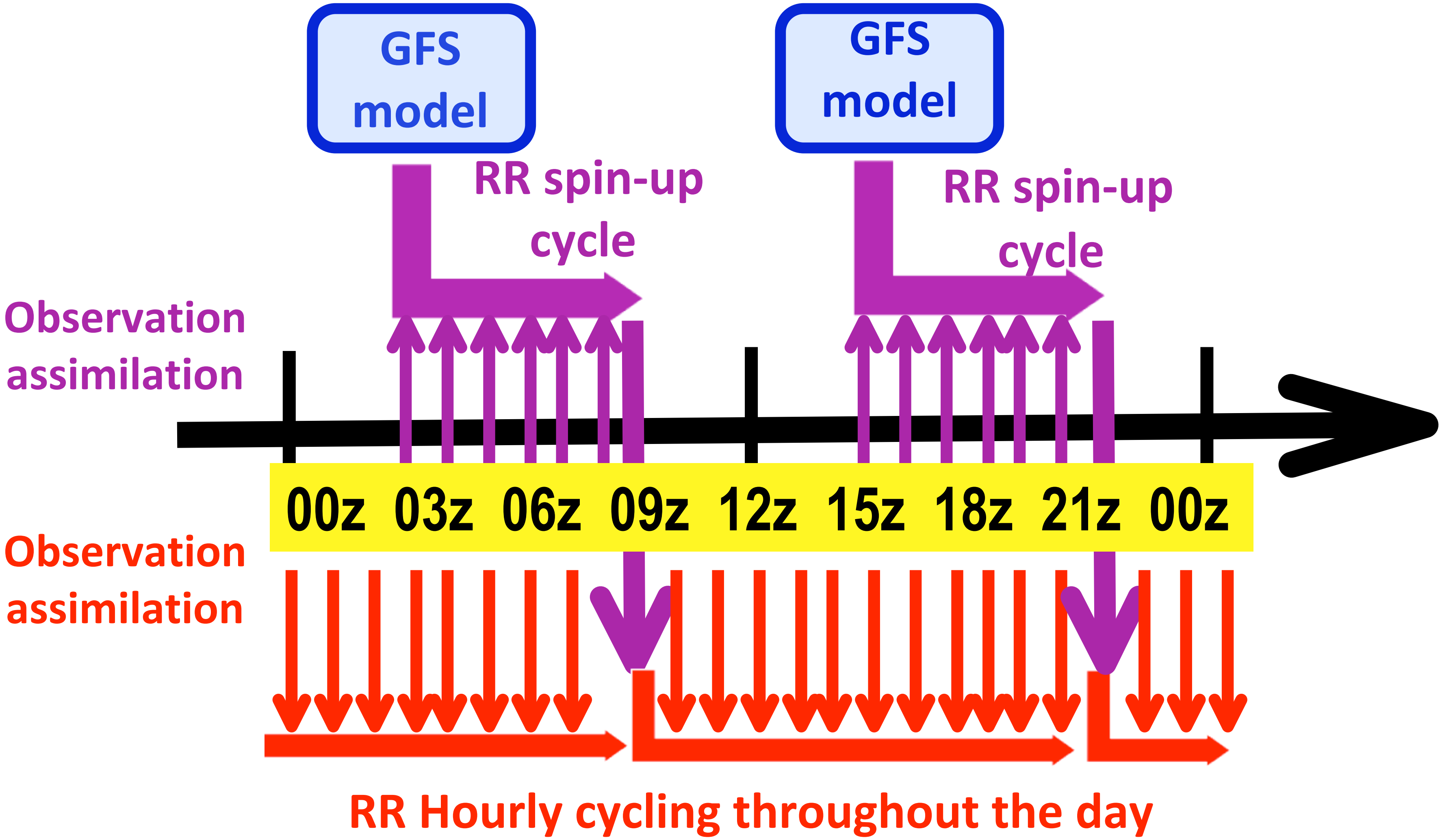
Comments and Questions?

From analysis to forecast



- Smooth transition from analysis to forecast
- Storm merger not well handled (resolved?)

Rapid Refresh Partial Cycling



- Hourly cycling of land surface model fields
- 6 hour spin-up cycle for hydrometeors, surface fields

NOAA/ESRL/GSD/AMB Models

Model	Domain	Grid Points	Grid Spacing	Vertical Levels	Vertical Coordinate	Height Lowest Level	Pressure Top
RUC	**CONUS**	**451 x 337**	**13 km**	**50**	**Sigma/ Isentropic**	**5 m**	**~50 mb**
RR	**North America**	**758 x 567**	**13 km**	**50**	**Sigma**	**8 m**	**10 mb**
HRRR	**CONUS**	**1799 x 1059**	**3 km**	**50**	**Sigma**	**8 m**	**85 mb**

Model	Run at:	Time-Step	Forecast Length	Initialized	Boundary Conditions	Run Time	# of CPUs
RUC	NCEP oper	**18 s**	**18 hrs**	**Hourly (cycled)**	**NAM**	**~25 min**	**32**
RR	GSD, EMC	**60 s**	**18 hrs**	**Hourly (cycled)**	**GFS**	**~25 min**	**160**
HRRR	GSD	**15-20s**	**15 hrs**	**Hourly (no-cycle)**	**RUC (RR planned)**	**~50 min**	**1000**

Rapid Refresh vs. RUC (NCEP-oper) upper-air verification +6h forecast

RMS Error

27 Dec 2010 - 7 Jan 2011